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PROBABILITY WEATHER FORECASTS: FOR THE ARMY.(U)

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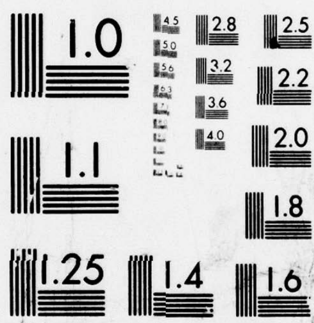

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The United States Army presently receives weather forecasts expressed in categorical terms. However, this forecast form limits the useful information that can be communicated to the decision maker. This study investigates the utility of replacing categorical forecasts with probability forecasts in order to enhance decision making by Army commanders. To this end, the advantages and limitations of probability forecasts are reviewed. The principal conclusion of this study is that Army commanders would benefit from receiving probability weather forecasts. Finally, several recommendations for smoothing the conversion are given and a briefing that a Staff Weather Officer can use as a basis for showing an Army commander the utility of probability forecasts is provided.

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PROBABILITY WEATHER FORECASTS: FOR THE ARMY?

A thesis presented to the Faculty of the U.S. Army
Command and General Staff College in partial
fulfillment of the requirements for the
degree

MASTER OF MILITARY ART AND SCIENCE

by

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1979

MASTER OF MILITARY ART AND SCIENCE

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ABSTRACT

PROBABILITY WEATHER FORECASTS: FOR THE ARMY? by Major Arthur C. Kyle, USAF, 106 pages.

The United States Army presently receives weather forecasts expressed in categorical terms. However, this forecast form limits the useful information that can be communicated to the decision maker. This study investigates the utility of replacing categorical forecasts with probability forecasts in order to enhance decision making by Army commanders. To this end, the advantages and limitations of probability forecasts are reviewed. The principal conclusion of this study is that Army commanders would benefit from receiving probability weather forecasts. Finally, several recommendations for smoothing the conversion are given and a briefing that a Staff Weather Officer can use as a basis for showing an Army commander the utility of probability forecasts is provided.

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> And therefore I say: "Know the enemy, know yourself; your victory will never be endangered. Know the ground, know the weather; your victory will then be total."[1]

INTRODUCTION

Background

History provides many examples of the effect of the environment on warfare.* In some cases, the military commander considered the weather in his planning and benefitted greatly. One example of an engagement in which weather was incorporated into the planning was Hitler's attack of France through Holland and Belgium. In Directive No. 8 for the Conduct of the War, he ordered his forces to be continually ready in order to "exploit favorable weather conditions immediately."[4] The German western offensive, originally scheduled for January, 1940, was postponed "on account of the meteorological situation."[5] It was Hitler's desire that the attack be supported by the Luftwaffe; hence, it would have to commence in favorable flying weather.[6] On the other hand, in many of history's campaigns, the commander ordered an attack without regard for the weather or else just had bad luck because of the

*Two excellent chronicles are Lieutenant Colonel Atkinson's Army War College paper, "Impact of Weather on Military Operations: Past, Present, Future"[2] and Military Airlift Command historian John Fuller's "Weather and War."[3]

weather. For example, a violent wind storm in the English Channel was as much responsible for defeating the Spanish Armada as was the English Navy. On hearing of this, King Philip II of Spain reportedly said, "I sent them to fight the English, not storms."[7]

Since weather has influenced warfare in the past, it is logical to expect weather to affect warfare in the future. Indeed, the highly complex and sophisticated weapon systems the United States presently possesses are more greatly affected by the environment than were those used in previous wars. Consider, for example, the weapon systems used to destroy tanks. In World War II, the prime tank killer for the infantryman was the bazooka, which had an effective range of about 250 meters. Now, the infantryman can use the TOW (tube-launched, optically-tracked, wire-guided) antitank missile at a guidance range up to 3000 meters.[8] Visibility is thus a more critical factor for employment of the TOW.

Since the effectiveness of modern weapon systems is highly dependent on environmental conditions, the importance of weather knowledge to the military decision maker has increased.[9] Admiral Thomas Moorer (former Chairman of the Joint Chiefs of Staff) summarized this importance as follows:

> While weather has always been a factor in the prosecution of wars, that as military technology has advanced and become more complex, military operations have become more sensitive to the environment. One of the most difficult decisions facing the operational commander today is the selection of the optimum weapon systems

to be used. Such a decision can not be made without component weather advice.[10]

The military organization charged with providing environmental support* to the United States Army and the United States Air Force is Air Weather Service, a subordinate unit of the Military Airlift Command.[12] A major component of Air Weather Service support to decision makers is forecasting future atmospheric conditions. Air Weather Service forecast skill, as measured by locally issued terminal forecasts, increased during the 1950's and 1960's because of advances in weather observing equipment (e.g., radar and satellites) and improved capabilities of data processing equipment. In the past few years, however, forecast skill has gone up only slightly.[13] In fact, it has been suggested that the primary forecasting techniques in use today can not be improved.[14] In spite of this, today's decision makers, as shown earlier, demand more and better weather support. In order to provide improved weather forecast services, Air Weather Service personnel recently have suggested that Air Force decision makers be provided probability weather forecasts.[15] Current Air Weather Service policy agrees, stating that probability forecasts will be used "whenever such forecasts can benefit the customers."[16]

*Environmental services "encompasses only those scientific, technical, and advisory activities required to produce and supply information of the past, present, and future states of space and the atmospheric surroundings for use in military decision-making processes."[11]

This author agrees that Air Weather Service must enhance its support to decision makers by increasing the utility of its forecasts, even though appreciable increases of forecast skill may no longer be possible. In times of peace, the prevailing austere climate for the military dictates this. In times of war, the likelihood that the United States Army will have to fight outnumbered demands it.[17]

The author first recognized the need for a study such as this when he visited several Army units in Europe in order to evaluate the utility of a weather probability forecast bulletin developed for use during REFORGER 76.[18] He found that the product was used by only one commander. An improved probability forecast product was prepared for use during REFORGER 78. Once again, the decision makers did not use the product. The senior Air Weather Service unit in Germany reported afterward that a major problem which needs to be overcome is that the weather units' "customers' basic understanding of probability and decision theory is deficient."[19] The purpose of this study is to investigate the feasibility of the use of probability weather forecasts by Army decision makers.

Statement of the Problem

Can probability weather forecasts enhance decision making by Army commanders?

Objectives of the Study

Principal objectives are to: (1) demonstrate the importance of weather forecasts to Army operations, (2) review the staff responsibilities for providing weather information to the Army commander, (3) compare and contrast the present (categorical) and proposed (probability) weather forecast types, (4) demonstrate the utility of probability forecasts, (5) describe some problems which may inhibit the adoption of probability forecasts and offer some suggestions for overcoming them, and (6) develop a briefing that a Staff Weather Officer can use as a basis for showing an Army commander the utility of probability forecasts.

Limitations of the Study

This study will focus on tactical rather than garrison weather support. Also, this study will not be a primer on how to prepare probability weather forecasts.

Assumptions

The assumptions are: (1) Air Weather Service forecast skill will not significantly improve in the near future, (2) Air Weather Service forecasters can, with training and practice, prepare reliable and skillful probability forecasts for Army missions, and (3) Army decision makers will continue to be introduced to and encouraged to use quantitative decision-making techniques.

Organization of the Study

This study begins with a review of the evolution

of weather support to the Army and a detailed account of the importance of weather forecasts to Operation OVERLORD. Next is a description of the present Army weather support system and a brief summary of the author's discussions with U.S. Army Command and General Staff College students and faculty on the use of weather forecasts by a tactical commander. Chapter 3 presents the advantages of probability forecasts over the presently used categorical forecasts. In Chapter 4, potential obstacles to the adoption of probability forecasts are reviewed. The final chapter presents conclusions and recommendations.

CHAPTER 2

ARMY USE OF WEATHER FORECASTS

The previous chapter noted several examples in which weather affected historical battles. This chapter reviews how weather support to the U.S. Army evolved, gives an example of a commander's use of weather forecasts in his decision making process, presents Army doctrine on the use of weather, and concludes with some thoughts on the usefulness of weather forecasts by selected Command and General Staff College faculty members and students.

Evolution of Army Weather Support

The U.S. Army first began collecting and using weather data in 1814, when Surgeon General James Tilton directed his doctors along the frontier to maintaim a weather diary. These rudimentary records were primarily temperature and rainfall reports and were of more use to the settlers moving west than they were to the Army. The first weather observing and reporting network was established after the War Between the States. In 1870, the War Department assigned the weather observing responsibility to the Army Signal Corps.[1] Weather reports from about 30 Signal Corps units around the United States were collected by telegraph.[2]

One of the first Signal Corps weathermen was PFC

John P. Finley, who was dispatched to Kanses City to investigate the severe tornado outbreak of May 29 and 30, 1879. His report, published by the Secretary of War in 1881, more closely resembled a historical rather than a scientific report.[3] However, PFC Finley concluded his report with this astute remark on the utility of weather forecasts:

> The frost will come in spite of the prediction, so will the tornado, but to get the right information to the proper point before the occurrence of the dangerous phenomenon ... is the great desideratum.[4]

Although General Pershing had a meteorological staff with him in France,[5] the weathermen could not offer much assistance to the Allied Expeditionary Force in combating "General Mud."[6] In fact, it has been suggested that the German meteorological staff was superior to that of the Allies. The evidence given is that the Germans started their major campaigns in early summer, when the terrain provided the best footing.[7] It was during this period that the first great advances in forecasting were being developed by the Norwegians.[8]

The increased use of aviation after World War I, along with the development of massive and complex ground vehicles, caused weather forecasting to become very important.[9] As a consequence, the Army Air Corps Weather Service was established on July 1, 1937, removing most of the weather observing and forecasting responsibilities from the Signal Corps.[10] Shortly after World War II ended, the Army Air Corps Weather Service became the Air Weather Service.

Forecast for OVERLORD

The most famous example of a weatherman's contribution to a major military operation was the forecast support to OVERLORD, code name for the Allied invasion of Normandy. During the initial planning, Group Captain Stagg was appointed Chief Meteorologist for the Supreme Allied Commander.[11] His first task was to determine what forecasts were required. Since all three services--navy, army, and air--were vitally involved, each was asked, "What are the least favorable conditions in which your forces can operate successfully?"[12] Many factors had to be considered, but the ultimate answer came from the Supreme Commander, General Eisenhower:

> We wanted to cross the Channel with our convoys at night so that darkness would conceal the strength and direction of our several attacks. We wanted a moon for our airborne assaults. We needed approximately forty minutes of daylight preceding the ground assault to complete our bombing and preparatory bombardment. We had to attack on a relatively low tide because of beach obstacles which had to be removed while uncovered.[13]

With that guidance, the Supreme Headquarters Allied Expeditionary Force staff agreed on the specific moon, tide, and weather conditions necessary. After much study of historic weather maps, Group Captain Stagg determined that the most favorable months for acceptable landing weather along the Normandy coast were May, June, and July. However, the odds of favorable weather was uncomfortably low even during these months: 24 to 1 against for May, 13 to 1 against in June, and 33 to 1 against in July.[14]

Compounding the problem of making a correct forecast in the face of such odds was the fact that the forecast would have to be made several days prior to the time of landing. At least 24 hours would be required to get the invasion fleet of 5,000 ships to the right place.[15] To prepare for this, the meteorological staff began in February practicing making five day forecasts.[16] As the time for the decision drew closer, General Eisenhower asked that his staff be presented the five day forecasts, for he said:

> As the day will soon come when a weather forecast may be a critical factor in an important decision which I shall have to make, I want first-hand experience not just of the forecasts. I want to know my meteorological advisors and what they can do. I want to know when and how far I can really trust them.[17]

The Supreme Commander decided the invasion would be scheduled for June, for preparations were too substantial to be completed by May. As May, 1944, drew to an end, the meteorological staff was regretful that the invasion had not been launched during the preceding several weeks of favorable weather.[18]

June 5, 6, and 7 were the days in which the combination of tide, moon, and time of sunrise were acceptable to launch the invasion of German-held France. General Eisenhower said this was "a tense period, made even worse by the fact that the one thing that could give us this disastrous setback was entirely outside our control." The selection of which day "would depend upon weather forecasts."[19]

On June 2, General Eisenhower and his staff began meeting twice a day to hear the weather forecast for June 5

and consider its implications.[20] Early on the morning of the 4th, Group Captain Stagg informed General Eisenhower that the forecast for the morning of the 5th was for overcast clouds and strong winds. Several of the staff, including Admiral Ramsay and General Montgomery, thought that preparations for the mission had proceeded too far to stop them; they were against a delay. However, Air Chief Marshall Leigh Mallory said the forecast weather would prevent the air forces from completing their tasks. General Eisenhower concurred, saying, "If the air cannot operate we must postpone."[21]

The next conference to discuss the prospects for OVERLORD was held the following morning during very stormy weather. General Eisenhower described what happened as follows:

> When the conference started the first report given us by Group Captain Stagg and the Meteorologic Staff was that the bad conditions predicted the day before for the coast of France were actually prevailing there and that if we had persisted in the attempt to land on June 5 a major disaster would surely have resulted. This they probably told us to inspire more confidence in their next astonishing declaration, which was that by the following morning a period of relatively good weather, heretofore completely unexpected, would ensue, lasting probably thirty-six hours. ... I quickly announced the decision to go ahead with the attack on June 6.[22]

What was the German Army doing at this time? They had anticipated an invasion but were unsure of the timing. Captured staff members said that the German forces had been in a maximum state of readiness during May, when the suitable weather had occurred.[23] General Von Rundstedt, Commander-in-Chief in the West, reported to Hitler on May 30

that he did not look for an invasion any time soon. Even on June 4, the meteorologists for the Luftwaffe said the storm which was striking the coast would persist for several more days. As a result, air and naval reconnaissance of English sea ports was postponed.[24] Also, General Rommel decided to take advantage of the storm and visit his home for a few days.[25] Thus, one can speculate that the bad weather of June 5 was a blessing in disguise for the Allied invasion. Perhaps General Bradley made the most astute evaluation of the weather's impact on the invasion when he said, "In this capricious turn of the weather, we had found a Trojan horse."[26]

This detailed account of the decision process for Operation OVERLORD was presented to highlight the utility of weather forecasts to military decision makers. Several key points will be referred to in subsequent sections of this paper. Next is a discussion of how the U.S. Army presently receives weather information.

Army Weather Support

Field Manual 100-5 stresses the importance of seeing the battlefield and concentrating the proper force at the proper place in both the offense[27] and the defense.[28] Since the weather in which the battle is to be fought is an important factor in both fundamentals, weather is often referred to as a combat multiplier. Chapter 1 of this paper cited several historical examples of the effect of weather on warfare.

The United States Air Force has assigned the responsibility of providing the Army commander with weather information to the Air Weather Service.[29] The functions and responsibilities of the Air Force and Army are outlined in the joint Field Manual 31-3/Air Force Manual 105-4.[30]

In order to carry out its mission of providing weather support, the Air Weather Service assigns units to corps, divisions, and separate brigades.[31] Weather units are tailored (number of personnel and skills required) to meet the needs of the Army unit to which they are assigned. They train with the Army units in order to maintain the same state of readiness.[32]

Weather units provide three general types of weather data: observations (information of the existing weather conditions), forecasts (a statement of the expected weather conditions), and climatological information (a statistical summary of weather elements in terms of averages, extremes, and frequencies of occurrence, based on past observations).[33]

Within the Army, the Assistant Chief of Staff, Intelligence, G-2, has staff responsibility for providing the commander information on the weather.[34] A listing of the specific duties of the G-2 with respect to weather intelligence* is given in FM 31-3/AFM 105-4.[36] The commander of the weather unit, the Staff Weather Officer, is the interface between the G-2 and the weather unit.[37]

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*Weather intelligence is defined as "an analysis of the effect of weather upon our own forces and the enemy."[35]

How well does the weather support system work? It appears the organization described above is adequate. The joint manual on Army weather support, FM 31-3/AFM 105-4, is presently being rewritten, but the general organizational structure of Air Weather Service units which support the Army is not expected to change.[38]

However, the author does believe that there is a fundamental problem with Army weather support. This is that Army commanders do not always choose a course of action that best fits the forecast weather. There are two possible reasons for this: (1) the commander does not consider the effect of weather on his operation, and (2) the other factors (mission, enemy, terrain, and troops) considered in a decision-making process over-weigh the weather factor.

The Army attempts to prevent the first reason through a variety of means. First, FM 31-3/AFM 105-4 states that "A commander should consider all meteorological factors involved to determine how best to perform his mission."[39] Second, several Army publications suggest how various weather parameters (e.g., rain, fog, clouds, wind, temperature) affect Army operations. Examples are AR 115-10/AFR 105-3,[40] FM 31-3/AFM 105-4,[41] FM 30-5,[42] FM 21-33,[43] and FM 90-7.[44] In addition, Training Circular 30-11 was prepared to "provide the latest guidance to commanders, their staffs and other users on obtaining and utilizing tactical weather support."[45] Third, the Military Estimate and Decision Process taught at the Command and General Staff College includes the question, "What is the

effect of the weather?"[46] And finally, numerous authors have written about how weather affects warfare in Military Review.

The author first became aware that Army commanders do not always consider the weather when he visited six Air Weather Service units supporting the Army during REFORGER 76. The purpose of the trip was to evaluate the utility of a new weather support product. The author found that this new product was not used by Army decision makers, but the Staff Weather Officers at each unit could not always determine which of the two above reasons applied.

The author believes this basic problem needs to be investigated, because Air Weather Service constantly evaluates its support in order to identify "areas that are not cost or mission effective."[47] If weather forecasts are not used by the Army in tactical situations, or are treated as "nice to have," then the assignment of forecasters to Army weather support units might cease. Also, if weather forecasts are not used in the decision-making process now, then the investigation of the utility of probability forecasts need not be continued.

In order to gain insights on how the weather forecast affects an Army decision maker in a tactical situation, the author discussed the matter with Army officers assigned to Fort Leavenworth. The advantages and limitations of probability forecasts were discussed also. The following section is a summary of the findings.

Discussions on Army Weather Support

The author began talking Army weather support with classmates before starting this paper. In general, the question was, "How do you use the weather forecast in your decision making?" The answer usually was, "As a company commander, I was told what to do and when, so I did not consider the weather" and the dialogue ended there.

It became apparent that what was needed was a hypothetical setting, i.e., to "appoint" the officer to Division Commander and to provide several scenarios in which the forecast weather could affect the division. Appendix A contains the discussion scenarios used. This facilitated a discussion on how the weather affects an Army commander and what he is likely to do about it.

The author had interviews with a select 20 infantry, armor, and intelligence officers: Command and General Staff College students (Major), Department of Tactics faculty (Colonel and Lieutenant Colonel), Combined Arms Combat Development Activity staff (Lieutenant Colonel) and Brigadier General Arter, Deputy Commandant of the Command and General Staff College.

Findings: Use of Weather Forecasts. Most officers did not give a specific opinion on the proposed payoffs. The consensus was that a tactical decision can not be based solely on a weather forecast; mission, enemy, terrain, and troops (METT) almost always dictate the decision. Also, unit structure usually prohibits the shifting of weapon systems from one brigade to another. Finally, since the

enemy situation is an uncertainty, just as the weather 24 hours from now is, few changes should be made until more is known. However, an example given by one interviewee as to the importance of weather was the construction of a company fire trap. Ideally, the fire trap would be oriented to take maximum advantage of the effective ranges of the company's weapon systems and the terrain. But if the likelihood of fog is high, the company must set up its positions wherever they can see the enemy.

The "Other Considerations" section presented situations that were easier to answer. Most agreed that the weather in which the battle was expected would affect the composition of the covering force. For example, in fog or poor off-road trafficability, more infantry would be needed. More artillery would be needed under conditions that limit the use of attack helicopters and close air support. All agreed that trafficability is a most important consideration in the positioning of the Division Support Area and the Main Command Post (not necessarily so for the Tactical Command Post since it involves fewer vehicles). For any operation in which helicopters or fixed wing aircraft are to be used, the weather forecast will often be the most important element in the commander's decision equation.

The bulk of the time with each officer was spent in a general discussion of weather and its effect on the Army. The author always asked if the officer had thought much about what he would do in different weather situations.

Most answered that they had not. Two reasons were given: lack of instruction in schools on weather's effect and training exercise scheduling that minimizes "bad" weather. The former reason has been reinforced at the Command and General Staff College--the author knows of no war games that have not been played in "good" weather (e.g., unlimited visibility, good off-road trafficability, unhampered air missions). The explanation of why adverse weather is "factored out" is the same for both reasons--to accomplish more training. While the author can not disagree with this, he suggests that Army officers be challenged to consider fighting in various weather situations in order to make optimum use of their resources whatever the environment.

Another topic that was discussed was when and how the weather forecast was used by the Army. All officers agreed that a division commander and staff should receive weather forecasts when plans are being formulated. This allows the G-2 and G-3 to include weather in "war gaming" the proposed courses of action. However, only one officer said he would make his plans to go with a 12-24 hour forecast of incoming adverse weather; the rest said they would not react until the weather changed.

Findings: Use of Probability Forecasts. If the sample of Army officers interviewed by the author is representative of the whole Army, this paper need go no further. All with whom probability forecasts were discussed were completely in favor of them. The officers wanted probability

forecasts mainly for two reasons: to gain more information about what weather might occur and to keep the decision making where it belongs--with the commander. The interviewees were adamant about the latter. As stated earlier, weather is only one decision variable and the weatherman is not knowledgable in the others. Army commanders and staff do not want a Staff Weather Officer to tell them "You can't do that because the weather will be too bad." They would much rather be given the probability of adverse weather and then use this as another input into the decision making equation. Since there are few situations in which the weather forecast will dictate the Army commander's decision, there is a lesser need for categorical "yes or no" forecasting than is perhaps required by Air Force decision makers. Finally, all stated they understood the meaning of probability forecasts. However, the author does not believe that all Army officers do understand probability forecasts and how to use them or are aware of advantages other than the two stated above.

This chapter has reviewed the evolution of Army weather support, showed how General Eisenhower used his weathermen in proparing for the Normandy Invasion decision, presented Army doctrine on the use of weather information, and concluded with insights gained from discussing the use of weather forecasts with Army officers at Fort Leavenworth.

The purpose of this chapter was to demonstrate that the Army needs weather information in order to make tactical decisions. The next chapter will provide background on two

types of forecast services available from the Air Weather Service. It will compare these two types and show which could prove to be more advantageous to Army decision making. Chapter 4 will discuss the potential resistance to adoption of this methodology.

CHAPTER 3

CATEGORICAL AND PROBABILITY FORECASTS

The previous chapter told how weather support to the United States Army has evolved and presented an example of how the weather played an important role in a commander's decision making process. It also showed what contemporary field grade officers would do to take advantage of or to diminish the effect of weather on their mission. The question to be answered, after some preliminary words about forecast accuracy, is: What type of forecast can best fit the Army's needs?

Precision and Weather Forecasts

Early meteorologists believed that if the atmosphere's initial state and the equations of motion were known, predicting the future state of the atmosphere would be possible by solving the mathematics.[1] Modern meteorologists have doubts about this.

The first problem is that the initial state of the atmosphere can not be precisely defined. Almost all weather reporting stations are located near airports and major metropolitian areas. Thus, weather observations are not taken for much of the land areas and most ocean areas, in spite of recent advances in weather satellites. Also, those weather observations that are available do not necessarily represent the conditions between reporting stations.

Additional error is introduced by inaccuracies inherent in the instruments that measure atmospheric variables.

A second problem is the defining of atmospheric motion with equations. While equations can be written that describe the atmosphere's behavior,[2] the solutions to these equations do not produce perfect forecasts. There are two reasons for this: (1) as stated before, insufficient observations, and (2) important atmospheric processes must be ignored in order to mathematically solve the equations.[3] Indeed, it has been suggested that atmospheric processes are so complex that two theoretically identical initial states may not lead to the same follow-on states and that perfect forecasts, therefore, are impossible.[4] This is one reason given for the lack of improvement of forecasting skill in recent years.[5] This is not a new problem. In 1951, Professor Willett of the Massachuttes Institute of Technology stated that "there has been little or no real progress made during the past 40 years in the verification skill of ... the kind of forecasting which first received attention."[6]

Thus, even if the meteorological community had all the money it wanted to install observation sites and buy more and faster computers, there is little hope for significant improvements in forecast skill.[7] This does not mean that forecasters should quit trying to improve their forecasts. Rather, it means forecasters, and the users of these forecasts, must be aware that forecasts contain uncertainty.

For an example of the accuracy of weather forecasts, a summary of the forecasting state of the art for Air Weather Service is given in Appendix B.[8] In general, Appendix B shows that Air Weather Service forecasters perform adequately for short (0-3 hours) forecasts but that longer period (3-24 hours) forecasts are inadequate for most weather elements. It is questionable if the forecast capabilities meet the Army's accuracy requirements outlined in Army Regulation 115-10:

> Equipment and technique accuracy in tactical weather service operations will be accomplished to the extent possible commensurate with the operational requirement, economical feasibility, state-of-the-art and accuracy of communications provided.[9]

Also, these data show that forecasts for the most unusual and critical phenomena, such as low ceilings, low visibilities, severe thunderstorms, and freezing precipitation, are inadequate. This lends credence to the statement that "local forecasting accuracy varies inversely with weather severity."[10] The importance of this will be discussed later.

Forecast Types

A weather forecast is "a statement of expected weather conditions at a point, along a route, or within an area at a specified future time, or during a specified period."[11] There are two general types of forecasts: categorical and probability.

Categorical Forecasts. Categorical forecasts are defined by two terms--"deterministic" and "categorical." "Deterministic" means the forecaster issues a statement

"that a single unique event will occur, even though the forecaster knows an entire spectrum of events is possible."[12] An example is the statement, "It will rain tomorrow." The "categorical" part of categorical forecasts means the forecaster must divide the possible range in which a weather element may occur into finite intervals and then forecast one interval.[13] The categories of the Air Weather Service forecast system, shown in Table 1,[14] are an example.

Ceiling and Visibility Categories

Category	Cloud Ceiling (feet)	Visibility (statute miles)
A	< 200	$< \frac{1}{2}$
B	200 to < 1000	$\frac{1}{2}$ to < 2
C	1000 to < 3000	2 to < 3
D	≥ 3000	≥ 3

TABLE 1

Probability Forecasts. Probability forecasts are "meteorological advice consisting of two parts--a well defined weather event and the expectation that the event will occur."[15] Probability values may vary from 0% to 100%. A probability forecast may be either subjective, objective, or climatological. These forecast types refer to how the probability forecast was prepared.

Subjective probability forecasts are prepared by individuals. They reflect a forecaster's confidence that a particular weather event will occur. Since each forecast is determined from an individual's assessment of a particular weather situation, subjective probability forecasts

may not be reproducible.[16] An example is the television weatherman's statement, "Probability of snow is 80%."

Objective probability forecasts are generally prepared by computers, using a predetermined set of rules.[17] Thus, they do not depend on the experience or judgement of an individual. The key requirement of objective probability forecasts is that a single forecast is possible from a given set of weather data.[18] One example is a forecast prepared by multiple linear regression[19]--the use of statistical methods to determine that City A has a 60% probability of a thunderstorm one hour after the temperature reaches 95 whenever the relative humidity is 80% or higher.

Since climatological data consist of "weather conditions and variations from normal for a particular place or area during a specified period of the year,"[20] a climatological forecast is a forecast that a weather event will occur as often as it has historically.[21] Climatological forecasts are most useful for supporting long range (greater than 7 days) operational planning.[22]

Because the three probability forecasts types are different only in the way they are derived, a decision maker would not likely know which type he was given. Nor should he care, since the principals of probabilities apply to all three types. Therefore, the descriptions and examples of probability forecasts used in this thesis are true for subjective, objective, and climatological probability forecasts.

Before the characteristics and utility of probability forecasts are shown, some attributes of categorical forecasts will be discussed. This is necessary in order to compare and contrast the forecasts presently used (categorical) with those proposed in this paper (probability).

Categorical Forecasts

As was learned from the definition, categorical forecasts give the impression of precision, certitude, and accuracy. Thus, they mask uncertainty, even though there is some uncertainty in the forecast. For example, the forecaster may be absolutely certain it will rain or he may think rain is only slightly more likely than no rain. But this distinction can not be handled by categorical forecasts. This means that the forecaster does not impart all he knows about a weather situation to the decision maker.[23] If the forecaster wishes to communicate that he is not overly confident in his forecast, he must resort to vague terms, such as "slight chance of" or "possibly."[24] Because these terms can mean different things to different people, the result is often a confused decision maker.[25] This deficiency can be especially critical if the forecast is interpreted differently by two decision makers, such as the ground commander who thinks the weather will be good enough for close air support but the air commander does not.

Another attribute of categorical forecasts is that the forecaster, in order to maximize his verification score, will forecast the category most likely to occur.[26] Even

though Air Weather Service forecasters are required to become familiar with the mission and environmental requirements of their operational customers,[27] forecasters are most aware of their verification statistics. And forecasters are graded by how well they fit the categories shown in Table 1.[28] Hence, a forecaster might be tempted to slant his forecast toward the verification category of his choice, rather than forecast for his customer's requirements.

There are times when a forecaster does not forecast the most likely weather event. This is generally when a rare event, such as hail, is possible. However, because he knows his customer must have sufficient warning of the possibility of damaging hail in order to complete protective actions, the forecaster must issue a hail forecast 30-60 minutes before the hail is expected (see Appendix B for hail forecast capabilities and limitations). Therefore, a forecast is issued for hail even though the likelihood of hail is small. The decision maker assumes hail will certainly occur and takes his protective actions.

What has resulted in this hypothetical, but realistic, scenario is what the author considers is the most serious deficiency of categorical forecasts--the forecaster has assumed the role of decision maker. It was the forecaster who, on his own, determined that the hail threat to the customer's operation was sufficiently high to warrant the protective actions. In most cases, the forecaster does not have adequate knowledge of the operation (e.g., cost of

protecting, cost of possible damage, impact on the mission, etc.) to be the one who decides when to take action.

Finally, because categorical forecasts imply certainty, they can not be effectively used with quantitative decision-making techniques.[29] Several decision theory techniques which may be of use to Army decision makers will be discussed later.

Probability Forecasts

Providing weather forecasts in terms of probabilities or "confidence factors" is not a new concept. In 1906, it was suggested that a number between one ("very doubtful") and five ("certainty"), when added to a forecast, would signify the forecaster's confidence.[30] While in France, General Pershing's meteorological staff used a similar confidence weighting system.[31] Confidence factors were not used in conjunction with weather forecasts much after that. Although there were limited attempts to use probabilities prior to 1965, this was the year the United States National Weather Service modified their forecasting policy to permit the issuing of probability of precipitation forecasts.[32]

The first point to be made in a discussion of probability forecasts is that phrasing a weather forecast in terms of probabilities does not automatically improve the accuracy of the forecast. The difficulties in weather forecasting described earlier still apply.

However, an attribute of probability forecasts is

that the forecaster has a means for conveying whatever uncertainty he may have to the user of his forecasts. This also means the forecaster can fully describe all possible outcomes.[33] For example, rather than saying categorically, "It will not rain," the forecaster can say, "The probability of rain is 30%."

As can be seen from this example, another attribute is that there is only one interpretation of probability forecasts. The laws of probability require that if the probability of rain is 30%, the probability of "no rain" is 70%.[34] In addition, the forecasts present the same meaning to all users. The forecast "30% probability of rain" always, to all users, means "30%." The qualifying words "slight chance of," sometimes used with categorical forecasts, can be avoided.

Finally, when issuing probability forecasts, the forecaster is concerned only with making his best forecast of the future state of the atmosphere. The only requirements are that the mathematical laws of probability be followed and that the forecast be the best judgement of the meteorological situation.[35]

These descriptions of the two forecast types, categorical and probability, were provided as background for the next section. For the purpose of this paper, it is the most important section.

Reasons for Changing to Probability Forecasts

Two reasons for changing the method of providing

weather support to the Army commander from categorical to probability forecasts are: (1) to improve the role of the forecaster, and (2) to enhance the use of weather forecasts. While the latter is the most important, the former will be discussed first.

Impact on Forecasters. As stated earlier, probability forecasts are an excellent means by which the forecaster can relay his uncertainty to the decision maker in concise, consistent terms. In other words, with probability forecasts, the forecaster is able to inform the decision maker when the forecast is a "sure thing" and when it is merely an educated guess.[36] The importance of this was evident during Operation OVERLORD when General Eisenhower wanted to know more than just the forecast--he wanted to know when he could trust the forecasters.[37]

Probability forecasts allow the forecaster to concentrate on the weather rather than the decision. This does not mean the forecaster does not care about the decision or about providing information toward a correct decision. Instead, it means the forecaster recognizes that he does not need to have a complete knowledge of the course of action being considered in order to provide an information structure.[38] While the forecaster may know the weather sensitivities of the mission being considered, he most likely will not know a very important component of the decision: the criticalness of the mission. Only the decision maker knows this, and, therefore, he should be allowed to make the decision without feeling his only choices

are to accept or ignore the forecast. As an example, a division commander is consedering using an attack helicopter platoon at a certain location on the battlefield. If the Staff Weather Officer believes there is a 60% probability that the weather will be unfavorable for helicopter operations, he would either say, "The weather will be unfavorable" or "The probability of favorable weather is 40%." The former is a categorical forecast and gives the division commander the options of not sending the helicopters (which means the weatherman influenced the decision perhaps too much) or rejecting the forecast. If the commander makes a practice of disbelieving the forecast, he may take undue risks. On the other hand, the commander can weigh the probability forecast along with the importance of the mission and make his own decision.

An additional benefit of probability forecasts is that, by definition, they must be for a specific event (e.g., probablilty of surface visibility greater than 3 km at grid point AB1234 for the next 3 hours is 90%). Thus, by letting the forecaster know exactly what weather events are important to him, the commander can receive only those forecasts. Commanders recognized during World War II that they needed forecasts that were specific and applicable to the particular situation,[39] and this will be even more important on the battlefield of the future. No longer can the commander allow the weatherman to spend 5-10 minutes describing present and future weather events in broad generalities, using terms that are meaningless or useless

to the commander. By providing probability forecasts for important weather events and specific thresholds, preferably in a grided template format, the weatherman can impart a maximum of weather intelligence in a minimum of time.[40]

Enhance Utility of Forecasts. The primary reason for changing to probability forecasts is that they can enhance decision making. Probability forecasts (1) provide more information, (2) are consistent, (3) can be used with quantitative decision-making techniques, and (4) can be more cost and/or mission effective in the long term. Each of these are "fleshed out" below.

If forecasters could make perfect forecasts, they could provide categorical forecasts to decision makers. The decision makers could then choose a course of action with certainty. As was shown earlier in this chapter, forecasters can not consistently make perfect forecasts. Thus, by using probability forecasts, a commander can consider forecast uncertainty in his decision making process. For example, a division commander wants to travel by helicopter to discuss the current situation with the commanders of the 1st Brigade and the 3d Brigade. If he considers both conferences equally important but can visit only one brigade command post, the deciding factor in which command post he flies to may be the enroute weather. The Staff Weather Officer forecasts a 40% probability of favorable enroute weather to the 1st Brigade and a 5% probability of favorable enroute weather to the 3d Brigade. Since a categorical forecast to either command post would be for unfavorable

weather, the division commander has more information with the forecast in probabilistic terms. It is likely that in this situation he would choose to visit the 1st Brigade.

There are some circumstances in which the weather event in which the decision maker is interested is so rare that seldom, if ever, would a forecaster make a categorical forecast for the event. This is because the forecaster will be forecasting the category that is most likely to occur. In most areas of the world, severe weather (e.g., very low visibility, high winds, or hail) occurs very infrequently. However, it is this type of weather for which the decision maker needs prior warning. Unless the forecaster can use probabilities, advance warning may never be given. Or if it is, it is done because the forecaster used his own utility values.

A decision maker who used probability forecasts for a rare weather event was the commander of the Space and Missile Test Center at Vandenberg Air Force Base, California. He had the requirement to launch several Minuteman ballistic missiles into areas of the Pacific Ocean in which clouds were present.[41] Because the average frequency of the desired weather conditions was only 10%, it was highly unlikely that the Staff Weather Officer would have been able to identify a situation in which he had the confidence to issue a categorical forecast for the desired weather. Thus, probability forecasts were issued, and the commander made a "Go" decision whenever the forecast was 20% or greater.[42]

A second advantage of probability weather forecasts to the decision maker is that probability forecasts, because they are well defined in mathematical terms, mean the same to all users. The importance of decision makers at all echelons receiving the same forecast was mentioned earlier. Consistent interpretation is also a must.[43]

A third advantage is that probability weather forecasts can be used with quantitative decision-making techniques. These techniques were designed to be used in situations in which uncertainty must be taken into account.[44] To a decision maker, uncertainty is "the gap between what is known and what needs to be known to make correct decisions."[45] Thus, the decision maker's problem is to "minimize the cost of uncertainty in terms of the net expected utility of purposive, deliberate conduct."[46]

Use of quantitative decision-making techniques has become popular in recent years. Techniques have been developed under several disciplines: Operational Research, Management Science, Systems Analysis, and Decision Theory. This paper is not concerned with the finer points that distinguish these methods, but it is sufficient to say that the common thread is the formal use of logic and objectivity in decision making.[47] The objective of each is to provide a framework for using available information to choose the "best" course of action in accordance with the decision maker's preferences.[48]

Army officers are introduced to quantitative decision-making techniques at the Command and General Staff

College[49] and the Army War College.[50] Indeed, a study of the decision making process of Army Field Grade officers concluded that most "support the concept of the existence of a decision making process (in one form or another), and make a concerted effort toward its successful application."[51]

The following examples demonstrate the applicability of two of the many quantitative techniques available to Army decision makers who must choose between courses of action affected by the weather.

A division is succeeding in its attack. In fact, the commander sees the 1st Brigade is on the verge of making a breakthrough. In order to take advantage of the situation, the commander wants to send a battalion size force to capture a vital river crossing which is now 20 km behind the front lines. The G-3 proposes three courses of action for securing the bridge: (1) Send an airborne battalion, (2) Send in a battalion via helicopters, and (3) Have a task force of the 1st Brigade press forward at maximum speed. Since speed is of the utmost importance in capturing the bridge, the commander would prefer to use either Course of Action 1 or 2. However, the weather and the enemy's air defense capabilities affect these options. The G-2 reports that the enemy's radar weapons have been destroyed, but that he still has surface-to-air missiles that can be fired visually. Weather necessary for the airborne landing would be a ceiling of at least 3000 feet and 3 miles visibility. The air assault helicopters could fly low level, as long as the ceiling were above 100 feet and visibility

at least 1 mile. The maneuver task force could go in any weather. For these courses of action, ceiling/visibility of 3000 feet/3 miles or greater will be called Type A weather, from 100 feet/1 mile to 3000 feet/3 miles will be called Type B, and Type C will be dense fog.

Since the success of each course of action depends on the weather which occurs, the commander assesses the relative utility of each course of action with respect to the weather on a scale of 0 (worst) to 10 (best) as follows:

C/A 1 chosen/Type A weather occurs: This is the optimum weather for the airborne mission. However, the aircraft will be most vulnerable to the enemy's air defense weapons, so some losses are expected. Commander assigns a utility of 8.

C/A 1 chosen/Type B weather occurs: The clouds which hide the aircraft from the enemy's antiair weapons will also reduce the accuracy of the troops to reach the desired area. Commander assigns a utility of 5.

C/A 1 chosen/Type C weather occurs: Troops will not be able to make the jump. Commander assigns a utility of 0.

C/A 2 chosen/Type A weather occurs: Assault can be accomplished, but some aircraft losses must be expected due to good visibility for enemy air defense. Commander assigns a utility of 6.

C/A 2 chosen/Type B weather occurs: Clouds and visibility low enough to hinder enemy air defense, but not low enough to prevent mission. Commander assigns a utility of 10.

C/A 2 chosen/Type C weather occurs: Fog obscures terrain to such an extent that mission is impossible. Commander assigns a utility of 0.

C/A 3 chosen/Type A weather occurs: Weather does not affect the task force, but it can not complete mission as fast as the commander wants. He assigns a utility of 3.

C/A 3 chosen/Type B weather occurs: Weather does not affect the task force, but it can not complete mission as fast as the commander wants. He assigns a utility of 3.

C/A 3 chosen/Type C weather occurs: Fog will hide the attack of the task force and should allow it to accomplish the mission quicker. Commander assigns a utility of 5.

The decision process can be summarized in a matrix:

Decision Matrix for Capturing River Crossing

		Weather		
		Type A	Type B	Type C
Commander's Decision	C/A 1	8	5	0
	C/A 2	6	10	0
	C/A 3	3	3	5

TABLE 2

Since the commander has accounted for the effects of METT (mission, enemy, terrain, and troops) in his assignment of the utility values, he is ready to use the weather forecast to choose the course of action. Given a weather forecast of 70% probability of Type A weather, 20% probability of Type B weather and 10% probability of Type C weather, the expected value (the sum of each outcome weighed by its associated probability[52]) of each C/A can be computed.

C/A 1: $8 \times .7 + 5 \times .2 + 0 \times .1 = 6.6$

C/A 2: $6 \times .7 + 10 \times .2 + 0 \times .1 = 6.2$

C/A 3: $3 \times .7 + 3 \times .2 + 5 \times .1 = 3.2$

Hence, given this probability forecast, the commander should choose the course of action with the highest expected value--the airborne mission. Note that if the forecaster had been using categorical forecasts, he would likely have said, "Type A weather will occur." The commander would then assume this meant "Type A will occur with certainty" and would surely have chosen C/A 1.

Suppose the forecast had been for 60% probability of Type A weather and 40% probability of Type B weather. The expected values become:

C/A 1: $8 \times .6 + 5 \times .4 + 0 \times 0 = 6.8$

C/A 2: $6 \times .6 + 10 \times .4 + 0 \times 0 = 7.6$

C/A 3: $3 \times .6 + 3 \times .4 + 5 \times 0 = 3.0$

The commander now should choose Course of Action 2. Given these probabilities, a forecaster would likely have issued a categorical forecast for Type A weather and would have induced the commander into choosing Course of Action 1. However, because the commander has analyzed the factors affecting the mission and assigned utilities to the possible outcomes, he finds that he is better off to choose Course of Action 2 when Type B weather is only slightly less likely than Type A weather. The commander would know this only if the forecaster is allowed to quantify the uncertainty in his prediction.

A decision maker often must choose between taking or not taking a particular course of action. The most frequent example with respect to weather is the decision to protect or not protect aircraft from potentially damaging elements such as hail, strong winds, or freezing rain.[53] In this case, the utility matrix can be simplified into a 2 X 2 matrix:

Decision Matrix for Protecting from Damaging Weather

		States of Weather		
		Unfavorable	Favorable	Expected Value
Courses of Action	Protect	A	B	PxA + (1.0-P)xB
	Do not Protect	C	D	PxC + (1.0-P)xD
Forecast Probability		P	1.0-P	

TABLE 3

The quantities A, B, C, and D can be either utilities assigned by the decision maker or the dollar cost to take the protective actions and the cost of potential damage. Rather then computing the expected value of each course of action, it can be shown that the decision maker can compute his critical probability (the probability above which it is cost or mission effective to take action[54]) as follows:

$$P_c = \frac{C - D}{B + C - A - D}$$

The rules for making the decision, given a forecast probability of unfavorable weather of P, are:[55]

Protect if $P > P_c$

Do not protect if $P < P_c$

Do either if $P = P_c$

Quite often the decision process can be simplified further. If it is assumed that the resources are completely protected against adverse weather if the protective actions are completed, A = B = the cost to protect the resources. Also, C = the loss expected if no protective actions are completed and D = 0. Thus, the critical probability is

the cost to protect divided by the potential loss, and the decision rules become:[56]

Protect if $P > A/C$

Do not protect if $P < A/C$

Do either if $P = A/C$

where $0 \leq A/C \leq 1.0$. Obviously, if the cost to protect is greater than the potential loss, the decision maker should never protect.

Finally, the most basic threshold value upon which to make a decision is to let P_c be the climatological probability of the weather element. This means the commander should take action whenever the forecast probability for the weather element is greater than its long term climatological frequency.

Another decision-making technique is the decision tree.[57] This method is generally used when a sequence of decisions and chance factors are present.

An example is a division commander's options of sending one or two infantry battalions to secure and hold key terrain. A simplified portion of the commander's thought process can be depicted as a decision tree as shown in Figure 1. Each square represents a decision point (commander chooses a course of action) and each circle represents a chance point (something over which the commander has no control but can obtain a probability of occurrence). To use this technique, the commander (or his staff) must assign a relative utility to each of the chance elements

Decision Process for Taking and Holding Key Terrain

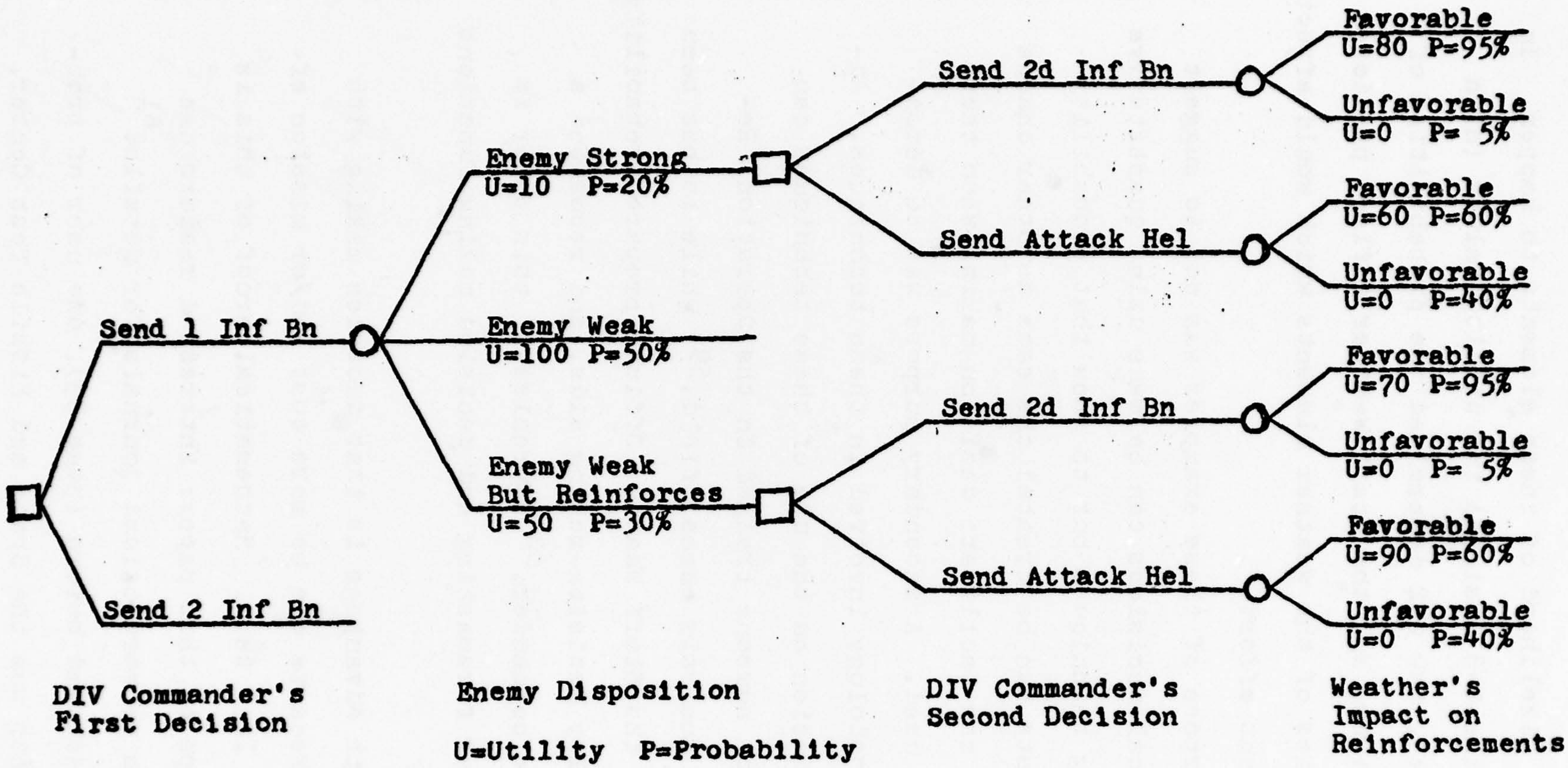

FIGURE 1

and assess the likelihood of these elements to happen. In this example, the G-3 assigned the utility values (high values are best), the G-2 determined the probabilities of enemy dispositions, and the Staff Weather Officer predicted the probabilities of the weather elements which would affect the reinforcement effort.

The purpose of these examples was not to suggest that all tactical decisions can be made using quantitative decision-making techniques but to show that probability weather forecasts can be treated the same as other chance elements[58] and can facilitate decision making when these techniques are used. A secondary purpose was to demonstrate the methodology involved in these techniques. Additional information on the use of these techniques can be obtained from someone trained in the Operations Research/Systems Analysis career field.[59] While it has been suggested that the Staff Weather Officer prepare probability forecasts, employ decision-making aids, and recommend a decision to the commander,[60] a premise of this paper is that the weather forecasting and decision making functions be separate.

A fourth advantage is that decision making with probability forecasts can be more cost and/or mission effective in the long term. Mathematical proof of this is beyond the scope of this paper; interested readers can consult various meteorological journals for details.[61] However, as discussed before (page 33), one user of probability forecasts was the Space and Missile Test Center.

In a 14 month period, SAMTEC made Go/No go decisions with probability weather forecasts and found that the early termination of 18 missile countdowns when the probability of unfavorable weather exceeded the critical probability saved $3,200,000 in range support costs.[62]

In summary, this chapter discussed the uncertainty inherent in meteorological forecasts, described categorical and probability forecasts, and presented reasons for changing to probability forecasts. Overall, this chapter has demonstrated that probability weather forecasts can enhance decision making by Army commanders.

There remain some obstacles to the acceptance of probability forecasts by all decision makers. These will be discussed in the next chapter.

CHAPTER 4

OBSTACLES TO CHANGE

Previous chapters have shown that: (1) Army commanders require weather forecasts, (2) Air Weather Service provides weather forecasts to the Army, (3) weather forecasts contain uncertainty, (4) probability forecasts offer more advantages to decision makers than do categorical forecasts, and (5) a sampling of Army officers prefer receiving probability weather forecasts. However, there remain some obstacles preventing an immediate, complete change in the methodology that Air Weather Service (AWS) uses to provide forecasts to the Army.

This chapter will discuss the problems that have been, and are expected to continue to be, associated with a change to probability forecasts. These problems arise from the two groups most closely involved with the forecasts: the AWS forecasters and the Army users of the forecasts.

Internal Air Weather Service Problems

Air Weather Service hesitancy to adopt probability forecasts stems primarily from: (1) lack of an overall implementation plan, (2) forecaster reluctance to change, and (3) inability to show customers that the advantages of probability forecasts outweigh their disadvantages. Air Weather Service is working on these problems, but because of their

complexity, solutions will not be immediate. Therefore, each will be discussed in some detail.

Probability Implementation Plan. Air Weather Service forecasters have used probability forecasts to support their customers for years. However, these programs were the exception, not the rule. In general, they happened only when the forecaster advocated probability forecasts and his customer readily saw the advantages.

What is lacking is overall guidance from AWS Headquarters on when to, how to, and who should prepare probability forecasts. Since forecasters have different opinions on probability forecasts (these will be discussed in the next section), so too do the managers at Headquarters. Some offices have a "Let's do it now" attitude, others are completely opposed, and others are in favor of a gradual adoption of probability forecasts.

The need to resolve these differences and to start work toward an efficient transition toward probability forecasts has been recognized.[1] At this time, AWS Headquarters is drafting a comprehensive implementation plan for the use of probability forecasts by AWS forecasters. The need for this plan becomes obvious as one continues this chapter. The author believes this plan should be completed as soon as possible.

One fallout of the systematic implementation planning effort has been a change in AWS policy on the direction of the integration of probability forecasts from "into all aspects of weather support at all echelons"[2] to "into all

aspects of weather support whenever such forecasts can benefit the customer."[3] The increased emphasis on customer utility places the implementation of probability forecasts in the proper perspective.

<u>Forecaster Reluctance</u>. Forecasters, being human, are reluctant to change the way they have been doing business. They give a variety of reasons, such as "I'm better than that," "I don't know enough," and "That is too much work."

The first answer is caused by the connotations many have about the meaning of the concept of probabilities. Many forecasters believe that the use of probabilities is, at best, a way of hedging, or, at worst, a way of avoiding making a decision. These are the forecasters who prefer to avoid or suppress uncertainty through the use of categorical forecasts. However, as was shown earlier in this paper, uncertainty in weather forecasting exists for a multitude of reasons. In essence, these forecasters are not as good as they think they are.

Another factor delaying the adoption of probability forecasts is a feeling by forecasters that they do not have enough skill or knowledge to assign subjective probabilities to weather events.[4] Most AWS enlisted forecasters have not had formal education in probability theory, so they regard the process of assigning probability values to their weather forecasts as an impossible task. However, experiments have shown that individuals can, with some experience and practice, learn to describe their attitudes about a given situation.[5] In particular, a general knowledge of atmospheric

processes and forecasting experience carry an individual a long way toward issuing skillful probability forecasts.[6]

Both of these forecaster arguments against probability forecasts can be countered by education and training. To this end, Air Weather Service has published a pamphlet recommending forecast techniques[7] and has written two seminars: one for overall forecaster training[8] and another for Staff Weather Officers.[9] These publications point out the uncertainty inherent in weather observations and forecasts and emphasize that subjective probability forecasts are scientifically valid. The argument that forecasters with little formal mathematical training can not prepare skillful probability forecasts was largely dispelled by the results of the Forecast Skill Score Test. This test, conducted from October, 1977, to March, 1978, had 26 AWS units prepare approximately 100,000 probability forecasts. One of the major findings of the test was that "AWS forecasters can, with training and verification feedback, issue skillful probability forecasts."[10]

The third reason given for forecaster reluctance has been apprehension of increased workload. Units in the Forecast Skill Score Test found that little additional time is required to assign probability values, once the forecaster has analyzed the meteorological situation. The workload necessary to verify probability forecasts, however, is substantial. For this reason, verification at unit level should be kept at a minimum, with as much as possible being automated.

Inability to Show Advantages. One of the biggest obstacles AWS has faced has been convincing the users of its forecasts that probability forecasts enhance decision making. For years, AWS has emphasized the quality and value of its forecasts to top level Army and Air Force customers; that uncertainty is an ingredient of all forecasts has been downplayed or ignored. The natural result is that the users are reasonably happy with the forecast service. Thus, when a change is proposed, the customer wants to be convinced by unambiguous, relevant examples. To date, the best example showing the value of probability forecasts is the forecast support to missile launches at Vandenberg Air Force Base (page 42). As noted earlier, probability forecasts were prepared for decision makers during REFORGER 76 and REFORGER 78 but were not used. The author knows of no successful employment of probability forecasts to Army missions that would have universal application. To a large degree, this paper is an attempt to solve this problem.

User Problems

Since Air Weather Service has had difficulty in convincing the Army to accept probability weather forecasts, there must be definite obstacles to be overcome. Army acceptance has been hampered by reluctance to change, the fear of increased workload, and concern for the decision at hand (as opposed to all decisions to be made in the next year(s)).

User Reluctance. As forecasters are slow to accept change, so are their customers. Familiarity and varying

degrees of satisfaction with the categorical forecasts create an unwillingness to embrace probability forecasts. Further, the positive nature of categorical forecasts caters to the user's desire for a precise forecast; these forecasts positively and uniquely describe the future state of the atmosphere. This means the decision maker can act as though he had perfect information (information that is without uncertainty).[11] This, as was shown earlier, is not the case. The result is often that the forecaster assumes the role of decision maker. Some decision makers may prefer this; they then have a scapegoat for a wrong decision if the forecast misses, i.e., "The weatherman blew it again."

Army officers are not opposed to probabilities *per se*. Most are familiar with the concept even if they have not used probabilities in decision making. For example, the Intelligence Evaluation Rating System is used by Military Intelligence officers to evaluate the reliability and accuracy of their information. This system, in which reliability is rated from A to F and accuracy from 1 to 6, is a form of subjective probabilities.[12]

Increased Workload. Forecast users also fear probability forecasts will require them to do more. This is true. Since with probability forecasts the decision making responsibility is placed on the forecast user, he must know his operation and properly weigh the forecast against other decision factors. Quantitative decision-making techniques, as discussed in Chapter 3, are designed to help him. To

employ these techniques, however, he must be able to quantify his decision factors. In addition, he should use all information bearing on the decision at hand to determine his critical probability (page 39). The author believes the decisions that result from such a process will amply compensate for any extra effort.

Necessity to Avert Disasters. All decision makers want to make the correct decision. Ranking equally with this desire is aversion of an incorrect decision. The environment in which the military operates, as well as the natural longing to "do good," provide the impetus. This forces the commander to place his foremost attention on the next decision he must make. It is critical to the commander, therefore, that the forecast not be wrong. The problem arises when one remembers that a probability forecast can not be wrong unless it is 0% or 100%. Thus, theoretically, any probability forecast between 0% and 100% is not wrong. Clearly, a decision maker can not be faulted for having difficulty comprehending this, for he would likely choose different courses of action given a 5% or a 95% forecast, and either (or both) could be correct. Correct, that is, in the long run, i.e., after numerous forecasts have been compiled for grading. But the decision maker does not care about the long run, only his next decision.

This is a complex but important concept, as can be seen in the following examples. A commander can be faced with the decision of whether or not to protect his aircraft from severe weather. The necessary protective actions

(hangar or evacuate the aircraft) may be quite costly, but storm damage to unprotected aircraft will likely be more expensive. Further, he wants to avoid the wrath that might be forthcoming from higher echelon commanders because of the impact of out-of-commission aircraft on unit readiness. Therefore, the commander might not care that a forecast 5% probability of severe weather means that the severe weather will occur only one time in 20 similar weather situations. He reasons that he can not afford to take a chance on extensive damage while he has responsibility for the aircraft. Thus, he decides to protect at almost any cost, caring only about this decision, not the next 19. A tactical example would be a commander whose battalion must protect a vital avenue of approach. If fog is a frequent event in his area, the commander might deploy his troops very near the likely enemy approach route if he is given a 20% forecast of low visibility. He reasons that the outcome which could result from allowing the enemy to slip by under cover of the fog is too catastrophic for him to take a chance on a one time in five event. Both of these commanders, whether they know it or not, have chosen a very low critical probability upon which to threshold their decisions. This means they will be covered against the harmful event, but they should not blame the forecaster for missed forecasts when their protective action costs mount.

The author does not know how to circumvent this, except to suggest that perhaps an increased awareness by both the decision maker and the forecaster can ease the

situation somewhat. Also, increased communication between the two is required with probability forecasts. The forecaster must ensure he is giving forecasts for the critical weather element(s) and the decision maker must understand probability forecasts. The forecaster can also assist the decision maker in determining when and how to use the forecasts.

In conclusion, this chapter has outlined what the author believes are the most important obstacles inhibiting the use of probability forecasts by the Army. Can these obstacles be overcome? Can the Army use probability forecasts? The author's conclusions and recommendations are given in the next chapter.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The introduction of this study asked if probability forecasts could enhance decision making by Army commanders. Subsequent chapters have shown that Army decision makers require weather forecasts for certain tactical decisions and that uncertainty is present in all weather forecasts. It was also shown that the mathematical language of probabilities allows the forecaster to quantify his uncertainty and that probability weather forecasts are ideal inputs for quantitative decision-making techniques.

The principal conclusion, therefore, is that Army commanders would benefit from receiving probability weather forecasts. This conclusion is supported by both the discussions the author had with Army officers at Fort Leavenworth and the application of probability forecasts and quantitative decision-making techniques to Army situations. More work remains to be done, however, before Air Weather Service changes its mode of forecast support to the Army to probability forecasts. The next section contains the author's recommendations for the major actors: The Air Weather Service and the Army decision makers.

Additional conclusions on the use of weather forecasts by Army officers are:

1. Cognizance of weather's impact on warfare is directly proportional to the unit level in which an officer has served. Army officers who had been on a division staff were more aware than those who had been only at battalion level.

2. Army officers do not receive enough training in how weather affects tactical operations.

3. A commander must be aware of his mission's weather sensitivities before he can use probability weather forecasts. By definition, probabilities can only be given for specific events.

4. How an Army commander uses a weather forecast in his decision process is not always apparent to the Staff Weather Officer. It is frequently hard to see how the forecast affects the decision.

Recommendations

The basic recommendation of this paper is that Staff Weather Officers should pursue the integration of probability weather forecasts into Army weather support whenever these forecasts will benefit the decision makers. In order to overcome the obstacles to the adoption of probability forecasts identified in Chapter 4, several steps should be taken.

First, Air Weather Service should complete its probability implementation plan--a road map outlining the course AWS will follow in probabilistic forecast support. Included in this plan should be prospective applications for prob-

ability forecasts and the development of education and training aids for AWS forecasters. Both areas are important. AWS forecasters should know which Army (and Air Force) missions can best be supported by probability forecasts and must have the wherewithal to produce skillful probability forecasts. Also, Air Weather Service should endeavor to convince decision makers that improved weather support will result from probability forecasts. This can best be done by a program to educate Army commanders at all echelons on the advantages and use of probability forecasts. A first cut at such a briefing (text and slides) is given in Appendix C. While it was designed to be presented to a division commander, this briefing can be tailored to the level of its audience. In addition, AWS authors should periodically provide articles on Army use of weather service to Military Review. Of particular interest would be examples showing how probability forecasts were used by Army commanders in routine operations or during exercises.

Second, Army commanders and staff are encouraged to listen to the advantages and limitations of probability forecasts in order to determine if they can benefit from this service. The next step is to give probability forecasts a try. This may require additional education and training on the application of quantitative decision-making techniques. If the decision maker finds it difficult to use a probability forecast, he can easily convert it to a categorical forecast by choosing the category with the highest probability.

A final recommendation is that Army officers consider the impact of weather on all operations. This can be done in routine operations as well as in formal training. For example, in many situations an officer can ask himself, "What would I do different if the weather were __________?" To assist in this, more examples, both historic and simulated, should be added to Training Circular 30-11, Army Tactical Weather. After this, officers should be made aware of this publication and encouraged to read it.

In summary, probability forecasts can be more beneficial to Army commanders than categorical forecasts. Air Weather Service and the Army should work together in order that probability forecasts be added to the weather service provided to Army decision makers.

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APPENDIX A

APPENDIX A

DISCUSSION GUIDE

Subject: Army Use of Probability Forecasts

To:

1. FM 100-5 stresses the importance of seeing the battlefield and concentrating the proper force at the proper place in both offensive and defensive operations. Since the weather in which the battle is to be fought is an important factor in both fundamentals, weather is often referred to as a combat multiplier. This is justified, for history provides many examples of the effect of weather on warfare. In order to provide the Army commander with information on the present and future state of the weather, the USAF Air Weather Service assigns forecasters and observers to corps and division level units.

2. Many meteorologists currently believe that significant improvements in the art of forecasting the weather out to 48 hours are unlikely. Therefore, in order to improve weather support to the Army, a change may be necessary. It can be shown mathematically that the utility of weather forecasts to the decision maker can be enhanced if the decision maker is provided forecasts in probability terms. In a previous assignment at Hq Air Weather Service, I was frequently involved in discussions on the use of probability forecasts by the Air Force. Because of attending CGSC, Army weather support will be my next assignment(s). Therefore, my MMAS thesis seeks to answer the question, "Can probability forecasts enhance decision making by Army commanders?"

3. To assist in my investigation, I would like to discuss with you the use of weather forecasts by the Army and the implications of a change to probability forecasts for certain missions. Attachment 1 provides some scenarios and possible actions a division commander might make based on a weather forecast; it also discusses probability forecasts. I would appreciate about 20 minutes of your time, but I would be willing to talk about this as long as you desire.

4. We have an appointment for______________________________.

Arthur C. Kyle, Maj, USAF	1 Atch: Discussion Scenarios
Section 9

DISCUSSION SCENARIOS

1. <u>Situation</u>: You are commander of a division on the FEBA.

2. <u>Scenarios</u>: Consider the following scenarios. In each case, you receive a forecast 24 hours before the battle starts that a weather element in your 1st Bde area is to be unfavorable and acceptable conditions are predicted for the 2d Bde. Would you take any of the actions proposed? Are there other actions you would take, given the forecast? Does it make a difference if your mission is to attack or to defend?

a. Scenario I.

(1) Forecast: Visibility in the area occupied by 1st Bde to be 1 km or less for the first 24 hours of battle.

(2) Possible payoff: Move TOW systems from 1st Bde to 2d Bde; move some DRAGON systems and/or tanks to 1st Bde.

b. Scenario II.

(1) Forecast: Rain of such amount and rate in 1st Bde that trafficability will preclude tanks from maneuvering off roads for the first 24 hours of battle.

(2) Possible payoff: Deploy 1st Bde tanks to 2d Bde; replace with TOW and DRAGON teams.

c. Scenario III.

(1) Forecast: Visibility in area occupied by 1st Bde to be so low for the first 24 hours that forward observers will not be able to adjust artillery fires.

(2) Possible payoff: Move artillery to 2d Bde where forward observers will be able to direct fires effectively.

d. Scenario IV.

(1) Forecast: Temperature and wind conditions in 1st Bde for first 24 hours will cause smoke to disperse rapidly. Conditions for smoke better in 2d Bde area.

(2) Possible payoff: Divert smoke rounds from artillery supporting 1st Bde to artillery supporting 2d Bde.

e. Scenario V.

(1) Forecast: Clouds too low in 1st Bde area for first 24 hours to permit close air support.

(2) Possible payoff: Use CAS in 2d Bde area; shift artillery support to 1st Bde.

3. <u>Other Considerations:</u>

a. If Division is controlling the covering force, would you assign different units to your covering force if the 24 hour forecast were for poor visibility (1 km or less)? For poor off-road trafficability? For high winds (greater than 25 kts)? For low cloud cover?

b. Would forecast poor off-road trafficability affect your positioning of the Division Support Area? The TAC CP? The Main CP?

c. Are there any situations in which weather is a more important consideration in tactical planning than mission, enemy, terrain, or troops?

4. <u>Information on Probability Forecasts:</u>

a. Presently, the Staff Weather Officer provides categorical weather forecasts. This means the forecast is a statement that a specific event will/will not occur. Examples are: "The visibility will be 6 km or greater," "It will not rain," and "The temperature will not get lower than 35°" for a particular location and time.

b. A probability forecast is meteorological information consisting of two parts--a weather event and the expectation that the event will occur. Examples are "70% probability of visibility of 6 km or greater," "40% probability of rain," and "0% probability the temperature will be below 35°" for a particular location and time.

c. Advantages of probability forecasts:

(1) The forecaster is able to quantify his uncertainty.

(2) The forecast can be used with quantitative decision-making techniques.

(3) The forecaster can provide a complete description of the weather.

(4) The forecaster is concerned only with making the best weather forecast possible (not with making the operational decision also).

(5) The forecast is unbiased and consistent.

APPENDIX B

APPENDIX B

AIR WEATHER SERVICE

FORECASTING CAPABILITIES AND LIMITATIONS

1. Forecasting Capabilities.

a. Point Support.

(1) Terminal Weather.

(a)	Ceilings	
1.	200'-1500'	Acceptable (0-2 hr)
2.	1500'-4000'	Acceptable (0-3 hr)
(b)	Visibility	
1.	1-3 mile	Acceptable (0-4 hr)
2.	3-6 mile	Good (0-12 hr)
(c)	Wind speed 0-35 kt ± 5 kt	Good (0-10 kts - 85%, 0-24 hr)
(d)	Wind direction	Good (80%, 0-24 hr)
(e)	Precipitation	Acceptable (70%, 0-2 hr)
(f)	Fog, haze, smoke	Acceptable (70%, 0-2 hr)
(g)	Position/intensity (hurricane/typhoon)	Acceptable
(h)	Surface winds (hurricane/typhoon)	Good (90%, 1-3 hr; 85%, 3-6 hr) Acceptable (75%, 6-12 hr)
(i)	Pressure altitude (± 100 ft)	Good (90%, 1-12 hr)
(j)	Altimeter seeting (± 0.1 in)	Good (80%, 3-6 hr)

b. Area Support.

(1)	Contrails	Good
(2)	Diffusion	
(a)	Boundary layer	Acceptable (70% for 2 hr forecast)

1.	Temperature lapse rates	Good (80%, 2 hr); acceptable (60%, 2-12 hr)
2.	Wind speed	Good (90%, 2 hr); acceptable (75%, 2-6 hr)
3.	Wind direction	Acceptable (70%, 2 hr); inadequate (45%, 2-6 hr)

(b) Diffusion forecasts for weather modification

1.	Wind speed	Good (90%, 2 hr)
2.	Wind direction	Acceptable (70%, 2 hr)
3.	Comfort/stress	Good (80%, 1-6 hr)

(3) Wind profile

(a)	Paradrop winds	Good (80%, 1-12 hr)
(b)	Drop altitude winds	Good (80%, 1-12 hr)

2. Forecasting Limitations.

a. <u>Point Support</u>.

(1) <u>Target Weather</u>.

(a)	Thunderstorms	Inadequate (20%, for individual targets)
(b)	Precipitation	Inadequate (20%, 1-24 hr, individual targets)
(c)	Dust	Inadequate (10%, 1-24 hr, individual targets)
(d)	Fog, haze, smoke	Inadequate (35%, 1-24 hr, individual targets)
(e)	Cloud amounts	Inadequate
(f)	Cloud bases	Inadequate (10%, 12-24 hr)
(g)	Cloud tops	Inadequate (15%, 1-24 hr)
(h)	Visibility	Inadequate (30%, 1-24 hr)
(i)	Bomb altitude	Inadequate (40%, 1-24 hr)

(2) <u>Terminal Weather</u>.

(a) Ceilings

1.	0 feet	Inadequate (50%, 0-2 hr; 25%, 2-6 hr; 15%, 6-24 hr)
2.	100 feet	Inadequate (50%, 0-24 hr)
3.	200 feet	Inadequate (2-24 hr)
4.	500, 1000, 1500ft	Inadequate (2-24 hr)
5.	3000, 4000 feet	Inadequate (3-24 hr)

(b) Visibility

1.	0 feet	Inadequate (50%, 0-2 hr; 25%, 2-6 hr; 15%, 6-24 hr)
2.	150 feet RVR	Inadequate (50%, 0-2 hr)
3.	700 feet RVR	Inadequate (50%, 0-2 hr)
4.	1200 feet RVR	Inadequate (50%, 0-2 hr)
5.	2600 feet RVR	Inadequate (55%, 0-3 hr)
6.	1 mile	Inadequate (4-24 hr, 15% 24-48 hr)
7.	2, 3 mile	Inadequate (4-24 hr)

(c) Wind speed - aircraft launch/recovery

1.	0-35 kt ± 5 kt	Inadequate (15%, 0-24 hr)
2.	35-50 kt ± 5 kt	Inadequate (10%, 0-24 hr)
3.	50 kt ± 5 kt	Inadequate (0%, 0-24 hr)
4.	Weather modification	Inadequate (40%, 0-3 hr)

(d) Wind direction

1.	0-35 kts ± 20°	Inadequate (50%, 0-12 hr)
2.	35-50 kts ± 20°	Inadequate (40%, 0-12 hr)
3.	50 kts ± 20°	Inadequate (10%, 0-1 hr)

(e) Thunderstorms — Inadequate (40%, 0-1 hr; 20%, 1-3 hr)

(f) Severe Thunderstorm — Inadequate (20%, 0-3 hr)

(g)	Precipitation	Inadequate (30%, 2-24 hr)
(h)	Freezing precipitation	Inadequate (50%, 0-3 hr)

b. <u>Area Support</u>.

(1)	Tornado	Inadequate (40%, 1-3 hr)
(2)	Thunderstorm	Inadequate (35%, 1-3 hr; 20%, 3-12 hr)
(3)	Hail	Inadequate (25%, 1-3 hr; 15%, 3-12 hr)
(4)	Thunderstorm winds	Inadequate (30%, 1-3 hr)
(5)	Precipitation	
	(a) Drizzle	Inadequate (25%, 1-24 hr)
	(b) Rain, snow	Inadequate (35%, 1-24 hr)
	(c) Sleet	Inadequate (10%, 1-24 hr)
(6)	Clouds	
	(a) Amounts, bases	Inadequate (10%, 1-24 hr)
	(b) Tops	Inadequate (15%, 1-24 hr)
	(c) Types	Inadequate (50%, 1-24 hr)
(7)	Surface winds	Inadequate (50%, 1-24 hr)
(8)	Fog	Inadequate (50%, 1-24 hr)
(9)	Dust/blowing sand	Inadequate (25%, 1-24 hr)
(10)	Haze	Inadequate (45%, 1-24 hr)
(11)	Smoke	Inadequate (60%, 1-24 hr)
(12)	Surface temperature	Inadequate (50%, 1-24 hr)
	Surface humidity	Inadequate (40%, 1-24 hr)
(13)	Icing	Inadequate (45%, 1-24 hr)
(14)	Turbulence	Inadequate (35%, 1-24 hr)
(15)	Contrails	Good
(16)	Hurricane/typhoon	Acceptable

APPENDIX C

APPENDIX C

BRIEFING GUIDE

SLIDE 1.

SLIDE 2. Good morning, sir. The purpose of my briefing is to review the type of forecasts we presently provide and to propose a change to probability forecasts for certain missions. The objective of a change would be to improve our service and to enhance your decision-making.

SLIDE 3. I will cover these topics during the briefing.

SLIDE 4. Early meteorologists believed that if the atmosphere's initial state and the equations of motion were known, predicting the future state of the atmosphere would be possible by solving the mathematics. Modern meteorologists have doubts about this. The first problem is that the initial state of the atmosphere can not be precisely defined. Almost all weather reporting stations are located near airports and major metropolitian areas. Thus, weather observations are not taken for much of the land areas and most ocean areas, in spite of recent advances in weather satellites. Also, those weather observations that are available do not necessarily represent the conditions between reporting stations. Additional error is introduced by inaccuracies inherent in the instruments that measure atmospheric variables.

A second problem is the defining of atmospheric

motion with equations. While equations can be written that describe the atmosphere's behavior, the solutions to these equations do not produce perfect forecasts. There are two reasons for this: (1) as stated before, insufficient observations, and (2) important atmospheric processes must be ignored in order to mathematically solve the equations. Indeed, it has been suggested that atmospheric processes are so complex that two theoretically identical initial states may not lead to the same follow-on states and that perfect forecasts, therefore, are impossible. This is one reason given for the lack of improvement of forecasting skill in recent years. Thus, even if the meteorological community had all the money it wanted to install observation sites and buy more and faster computers, there is little hope for significant improvements in forecast skill. This does not mean that forecasters should quit trying to improve their forecasts. Rather, it means forecasters, and the users of these forecasts, must be aware that forecasts contain uncertainty.

SLIDE 5. Before proceeding, let me give some definitions. First, here is the definition of a weather forecast, taken from the joint Army/Air Force Manual, Weather Support for Field Army Tactical Operations. Next is categorical forecasts. Categorical forecasts are defined by two terms--"deterministic" and "categorical." "Deterministic" means the forecaster issues a statement that a single unique event will occur, even though the forecaster knows an entire spectrum of events is possible. An example is

the statement, "It will rain tomorrow." The "categorical" part of categorical forecasts means the forecaster must divide the possible range in which a weather element may occur into finite intervals and then forecast one interval. Air Weather Service has been issuing these forecasts for years. Finally, here is the official AWS definition of probability forecasts. Probability values may vary from 0% to 100%. A probability forecast may be either subjective, objective, or climatological. These forecast types refer to how the probability forecast was prepared.

Subjective probability forecasts are prepared by individuals. They reflect a forecaster's confidence that a particular weather event will occur. Since each forecast is determined from an individual's assessment of a particular weather situation, subjective probability forecasts may not be reproducible.

Objective probability forecasts are generally prepared by computers, using a predetermined set of rules. Thus, they do not depend on the experience or judgement of an individual. The key requirement of objective probability forecasts is that a single forecast is possible from a given set of weather data.

A climatological forecast is a forecast that a weather event will occur as often as it has historically. Climatological forecasts should be familiar as they are most useful for supporting long range operational planning. <u>SLIDE 6</u>. The best way to understand the difference between categorical and probability forecasts is to see

examples of both. I'm sure you have heard me and my people present categorical forecasts like these many times.. The probability forecasts have the same meaning as do the like numbered categorical forecasts.

SLIDE 7. The reasons I am proposing to change from categorical to probability forecasts will be easier to understand if I first review in some detail the characteristics of both forecast types. First, the categorical forecasts. As was learned from the definition, categorical forecasts give the impression of precision, certitude, and accuracy. Thus, they mask uncertainty, even though there is some uncertainty in the forecast. For example, the forecaster may be absolutely certain it will rain or he may think rain is only slightly more likely than no rain. But this distinction can not be handled by categorical forecasts. This means that the forecaster does not impart all he knows about a weather situation to the decision maker. If the forecaster wishes to communicate that he is not overly confident in his forecast, he must resort to vague terms, such as "slight chance of" or "possibly." Because these terms can mean different things to different people, the result is often a confused decision maker. This deficiency can be especially critical if the forecast is interpreted differently by two decision makers, such as the ground commander who thinks the weather will be good enough for close air support but the air commander does not.

Another attribute of categorical forecasts is that the forecaster, in order to maximize his verification score,

will forecast the category most likely to occur. Even though Air Weather Service forecasters are required to become familiar with the mission and environmental requirements of their operational customers, forecasters are most aware of their verification statistics. Hence, a forecaster might be tempted to slant his forecast toward the verification category of his choice, rather than forecast for his customer's requirements.

There are times when a forecaster does not forecast the most likely weather event. This is generally when a rare event, such as hail, is possible. However, because he knows his customer must have sufficient warning of the possibility of damaging hail in order to complete protective actions, the forecaster must issue a hail forecast 30-60 minutes before the hail is expected. Therefore, a forecast is issued for hail even though the likelihood of hail is small. The decision maker assumes hail will certainly occur and takes his protective actions. This means the forecaster has assumed the role of decision maker. It was the forecaster who, on his own, determined that the hail threat to the customer's operation was sufficiently high to warrant the protective actions. In most cases, the forecaster does not have adequate knowledge of the operation (e.g., cost of protecting, cost of possible damage, impact on the mission, etc.) to be the one who decides when to take action.

Finally, because categorical forecasts imply certainty, they can not be effectively used with quanti-

tative decision-making techniques. One technique which may be of use to Army decision makers will be discussed later.

SLIDE 8. The first point to be made in a discussion of probability forecasts is that phrasing a weather forecast in terms of probabilities does not automatically improve the accuracy of the forecast. The difficulties in weather forecasting described earlier still apply. However, an attribute of probability forecasts is that the forecaster has a means for conveying whatever uncertainty he may have to the user of his forecasts. This also means the forecaster can fully describe all possible outcomes. For example, rather than saying categorically, "It will not rain," the forecaster can say, "The probability of rain is 30%." Recall that in the examples shown earlier a forecast user got more information on the future state of the atmosphere from the probability forecasts. Another attribute is that there is only one interpretation of probability forecasts. The laws of probability require that if the probability of rain is 30%, the probability of "no rain" is 70%. In addition, the forecasts present the same meaning to all users. The forecast "30% probability of rain" always, to all users, means "30%." The qualifying words "slight chance of," sometimes used with categorical forecasts, can be avoided. When issuing probability forecasts, the forecaster is concerned only with making his best forecast of the future state of the atmosphere. The only requirements are that the mathematical laws of probability be followed and that the

forecast be the best judgement of the meteorological situation. Finally, probability forecasts are quite useful as inputs to quantitative decision-making techniques.

SLIDE 9. At this time, you may wonder what the Air Weather Service policy, or doctrine, is on the use of probability forecasts. Here is our policy statement.

SLIDE 10. Why has AWS adopted this policy? The answer is that probability forecasts have some advantages that categorical forecasts do not have. The advantages fall into these two broad headings, each of which I will discuss in some detail.

SLIDE 11. As stated earlier, probability forecasts are an excellent means by which the forecaster can relay his uncertainty to the decision maker in concise, consistent terms. In other words, with probability forecasts, the forecaster is able to inform the decision maker when the forecast is a "sure thing" and when it is merely an educated guess. Probability forecasts allow the forecaster to concentrate on the weather rather than the decision. This does not mean the forecaster does not care about the decision or about providing information toward a correct decision. Instead, it means the forecaster recognizes that he does not need to have a complete knowledge of the course of action being considered in order to provide an information structure. While the forecaster may know the weather sensitivities of the mission being considered, he most likely will not know a very important component of the decision: the criticalness of the mission. Only the

decision maker knows this, and, therefore, he should be allowed to make the decision without feeling his only choices are to accept or ignore the forecast. An additional benefit of probability forecasts is that, by definition, they must be for a specific event (e.g., probability of surface visibility greater than 3 km at grid point AB1234 for the next 3 hours is 90%). Thus, by letting the forecaster know exactly what weather events are important to him, the commander can receive only those forecasts. Commanders recognized in World War II that they needed forecasts that were specific and applicable to the particular situation, and this will be even more important on the battlefield of the future. No longer can the commander allow the weatherman to spend 5-10 minutes describing present and future weather events in broad generalities, using terms that are meaningless or useless to the commander. By providing probability forecasts for important weather events and specific thresholds, the weatherman can impart a maximum of weather intelligence in a minimum of time.

SLIDE 12. The primary reason for changing to probability forecasts is that they can enhance decision making. They do this in the ways shown here. If forecasters could make perfect forecasts, they could provide categorical forecasts to decision makers. The decision makers could then choose a course of action with certainty. As was shown earlier, forecasters can not consistently make perfect forecasts. Thus, by using probability forecasts, a

commander can consider forecast uncertainty in his decision making process. For example, a division commander might want to travel by helicopter to discuss the current situation with the commanders of the 1st Brigade and the 3d Brigade. If he considers both conferences equally important but can visit only one brigade command post, the deciding factor in which command post he flies to may be the enroute weather. The Staff Weather Officer forecasts a 40% probability of favorable enroute weather to the 1st Brigade and a 5% probability of favorable enroute weather to the 3d Brigade. Since a categorical forecast to either command post would be for unfavorable weather, the division commander has more information with the forecast in probabilistic terms. It is likely that in this situation he would choose to visit the 1st Brigade.

There are some circumstances in which the weather event in which the decision maker is interested is so rare that seldom, if ever, would a forecaster make a categorical forecast for the event. This is because the forecaster will be forecasting the category that is most likely to occur. In most areas of the world, severe weather, such as very low visibility, high winds, hail, occurs very infrequently. However, it is this type of weather for which the decision maker needs prior warning. Unless the forecaster can use probabilities, advance warning may never be given. Or if it is, it is done because the forecaster used his own utility values.

A second advantage of probability weather forecasts

to the decision maker is that probability forecasts, because they are well defined in mathematical terms, mean the same to all users. The importance of decision makers at all echelons receiving the same forecast was mentioned earlier. Consistent interpretation is also a must.

A third advantage is that probability weather forecasts can be used with quantitative decision-making techniques. These techniques were designed to be used in situations in which uncertainty must be taken into account. To a decision maker, uncertainty is "the gap between what is known and what needs to be known to make correct decisions."

A fourth advantage is that decision making with probability forecasts can be more cost and/or mission effective in the long term. I can obtain mathematical proof of this from AWS Headquarters if you or your staff are interested.

SLIDE 13. Now let me give you an example of how probability weather forecasts can be used in conjunction with quantitative decision-making techniques in a tactical situation. A division is succeeding in its attack. In fact, the commander sees the 1st Brigade is on the verge of making a breakthrough. In order to take advantage of the situation, the commander wants to send a battalion size force to capture a vital river crossing which is now 20 km behind the front lines. The G-3 proposes three courses of action for securing the bridge. The factors the commander must consider are the usual ones: mission, enemy,

terrain and weather, and troops. Since speed is of the utmost importance in capturing the bridge, the commander would prefer to use either Course of Action 1 or 2. However, the weather and the enemy's air defense capabilities affect these options. The G-2 reports that the enemy's radar weapons have been destroyed, but that he still has surface-to-air missiles that can be fired visually. There are known weather minimums necessary for an airborne mission and an air assault mission; these will be called Type A weather and Type B weather, respectively. Weather too bad for helicopter operations, such as a dense fog, will be called Type C.

SLIDE 14. Since the success of each course of action depends on the weather which occurs, the commander assesses the relative utility of each course of action with respect to the weather on a scale of 0 (worst) to 10 (best) as shown on this slide.

SLIDE 15. The commander's decision process can also be summarized in a matrix.

SLIDE 16. Since the commander has accounted for the effects of METT in his assignment of the utility values, he is ready to use the weather forecast to choose the course of action. Given the weather forecast shown, the expected value (the sum of each outcome weighted by its associated probability) of each course of action can be computed.

Hence, given this probability forecast, the commander should choose the course of action with the highest expected value--the airborne assault. Note that if the

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PROBABILITY WEATHER FORECASTS: FOR THE ARMY.(U)
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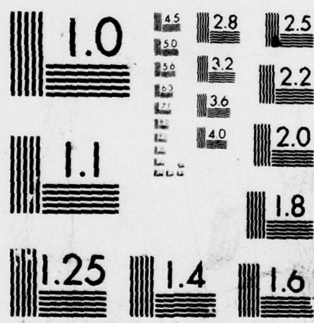

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

forecaster had been using categorical forecasts, he would likely have said, "Type A weather will occur." The commander would then assume this meant "Type A weather will occur with certainty" and would surely have chosen Course of Action 1.

SLIDE 17. Suppose the forecast had been for 60% probability of Type A weather and 40% probability of Type B weather. The expected value of each C/A changes, and, using the rule of choosing the C/A with the highest expected payoff, the commander goes with C/A 2. Given these probabilities, a forecaster would likely have issued a categorical forecast for Type A weather and would have induced the commander into choosing C/A 1. However, because the commander has analyzed the factors affecting the mission and assigned utilities to the possible outcomes, he finds he is better off to choose C/A 2 when Type B weather is only slightly less likely than Type A weather. The commander would know this only if the forecaster is allowed to quantify the uncertainty in his prediction.

SLIDE 18. A decision maker often must choose between taking or not taking a particular course of action. The most frequent example with respect to weather is the decision to protect or not protect aircraft from potentially damaging elements such as hail, strong winds, or freezing rain. In this case, the commander does not need to compute the expected value of both courses of action. Instead, he can compare the probability forecast with his predetermined critical probability, the probability above

which it is cost or mission effective to take action. Then he uses a decision algorithm such as that shown.

SLIDE 19. Since computation of the critical probability is important to decision making with probability forecasts, let me define it more precisely. The mathematical formula is shown here, along with the terms that are required. The quantities A, B, C, and D can be found in several ways. They may be the dollar values of expected gains and/or losses; they may be utility values determined by the commander as was done in the earlier example; they may be determined from computer models. Or the critical probability may simply be the climatological frequency of the weather event. For example, if adverse weather has a 30% climatology for a particular period, the commander may choose to execute his mission only whenever the forecast for that weather element is 20% or less.

SLIDE 20. We have discussed the advantages of probability weather forecasts. As with all things, there are also some potential problems that I will address at this time. The problems listed here have been, and are expected to continue to be, associated with probability forecasts. After I cover each of these, I will discuss some means for contending with them.

SLIDE 21. The first problem is that not everyone, including AWS forecasters, understands what probability forecasts mean. The National Weather Service has been providing probability forecasts to the public, via radio and television, for years. This is a compilation of the public's

interpretations of probability of precipitation forecasts that one researcher found. Number 6 is the official definition. Correct understanding is a problem both my people and yours will have to work on.

SLIDE 22. The second problem rests primarily within AWS, but it is obvious that how well we do will greatly affect our customer's acceptance of probability forecasts. In the past two years AWS has taken several steps to ensure our forecasters learn how to prepare skillful, reliable probability forecasts. Our Headquarters has published a "how to" seminar and pamphlet. In addition, they conducted a six month test in which 26 AWS units prepared approximately 100,000 probability forecasts. One of the major findings of the test was that our forecasters could issue skillful probability forecasts. The test also showed the value of practice and verification feedback, as the quality of the forecasts improved as the test progressed.

This is a good time to mention what is meant by the quality measurement terms "skillful and reliable." To start with, I must point out that we can not measure the quality of a single probability forecast. This relates to the problem of understanding probability forecasts. A single probability forecast can not be wrong unless it is for 0% or 100%. For intermediate values, we must batch together many forecasts of the same probability value and see for how many cases the weather event occurred. This is the measure of reliability. A forecaster is reliable, if, for example, a weather event occurred 6 out of the 20 times

he said, "30% probability of occurrence." That is our skill goal--to be reliable.

SLIDE 23. Air Weather Service has found that users are sometimes reluctant to accept probability forecasts because of fear of the unknown. A usual first assumption is that probability forecasts will mean more work. This is true. Since with probability forecasts the decision making responsibility is placed on the forecast user, he must know his operation and properly weigh the forecast against other decision factors. Quantitative decision-making techniques, as discussed earlier, are designed to help him. To employ these techniques, however, he must be able to quantify his decision factors. In addition, he should use all information bearing on the decision at hand to determine his critical probability. The payoff should be better decisions.

SLIDE 24. All decision makers want to make the correct decision. Ranking equally with this desire is aversion of an incorrect decision. The environment in which the military operates, as well as the natural longing to "do good," provide the impetus. This forces the commander to place his foremost attention on the next decision he must make. It is critical to the commander, therefore, that the forecast not be wrong. The problem arises when one remembers that a probability forecast can not be wrong unless it is 0% or 100%. Thus, theoretically, any probability forecast between 0% and 100% is not wrong. Clearly, a decision maker can not be faulted for having difficulty

comprehending this, for he would likely choose different courses of action given a 5% or a 95% forecast, and either (or both) could be correct. Correct, that is, in the long run, i.e., after numerous forecasts have been compiled for grading. But the decision maker does not care about the long run, only his next decision.

This is a difficult and most important concept, as can be seen in the following examples. A commander can be faced with the decision of whether or not to protect his aircraft from severe weather. The necessary protective actions (hangar or evacuate the aircraft) may be quite costly, but storm damage to unprotected aircraft will likely be more expensive. Further, he wants to avoid the wrath that might be forthcoming from higher echelon commanders because of the impact of out-of-commission aircraft on unit readiness. Therefore, the commander might not care that a forecast 5% probability of severe weather means that the severe weather will occur only one time in 20 similar weather situations. He reasons that he can not afford to take a chance on extensive damage while he has responsibility for the aircraft. Thus, he decides to protect at almost any cost, caring only about this decision, not the next 19. A tactical example would be a commander whose battalion must protect a vital avenue of approach. If fog is a frequent event in his area, the commander might deploy his troops very near the likely enemy approach route if he is given a 20% forecast of low visibility. He reasons that the outcome which could result

from allowing the enemy to slip by under cover of the fog is too catastrophic for him to take a chance on a one time in 5 event. Both of these commanders, whether they know it or not, have chosen a very low critical probability upon which to threshold their decisions. This means they will be covered against the harmful event, but they should not blame the forecaster for missed forecasts when their protective action costs mount.

SLIDE 25. The answer to these potential problems should be apparent. A new technique, just like a new piece of equipment, requires education, training and practice. We have to do it to learn it. My people need to practice issuing probability forecasts and you need to receive them and become comfortable making decisions with them. Most of all, we need to do what we are doing right now--talking to each other. We must be sure my people are giving what you need and your people are using the product in the optimum way. This means the forecaster and the user must have an open communication line.

SLIDE 26. The ultimate goal of every commander in combat is to win; correct decisions can provide the winning edge and probability forecasts can enhance decision making. To this end, I recommend we provide probability forecasts for the following missions (to be tailored to the requirements of the customer).

SLIDE 1 PROBABILITY WEATHER FORECASTS

SLIDE 2 PURPOSE

To demonstrate that probability weather forecasts can enhance decision making.

SLIDE 3 OUTLINE

Topics Discussed:
- --Uncertainty and weather forecasts
- --Categorical and probability forecasts
- --Reasons for changing to probability forecasts
- --Tactical example using probability forecasts
- --Potential problems
- --Methods for overcoming potential problems
- --Recommendation

SLIDE 4 WEATHER FORECASTS CONTAIN UNCERTAINTY BECAUSE

--The present state of the atmosphere can not be precisely defined.

--Mathematical equations describing atmospheric motion are hard to solve.

--Forecasters do not always interpret computer-derived forecasts correctly.

SLIDE 5 DEFINITIONS

Weather Forecast: "A statement of expected weather conditions at a point, along a route, or within an area at a specific future time, or during a specified period." (FM 31-3/AFM 105-4)

Categorical Forecast: A statement that a single unique category will occur after the possible ranges in which a weather element may occur have been divided into finite intervals.

Probability Forecast: "Meteorological advice consisting of two parts--a well defined weather event and the expectation that the event will occur." (AWSP 105-51)

SLIDE 6 EXAMPLES

Categorical Forecasts:

1. "The ceiling will improve to at least 1000 ft in 3 hrs."
2. "It will not rain this afternoon."
3. "Thunderstorms with ½ inch hail will hit in 30 minutes."

Probability Forecasts:

1. "There is a 90% probability of the ceiling being at least 1000 ft in 3 hrs."
2. "There is a 30% probability of rain this afternoon."
3. "There is a 60% probability of ½ inch hail in 30 min."

SLIDE 7 CHARACTERISTICS OF CATEGORICAL FORECASTS

--Imply precision, certitude, and accuracy.
--Forecasters will usually forecast the category they think is most likely to occur.
--Forecasters sometimes assume the role of decision maker.
--Can not be used with quantitative decision-making techniques.

SLIDE 8 CHARACTERISTICS OF PROBABILITY FORECASTS

--Do not improve accuracy.
--Provide complete description of possible weather.
--Consistent interpretation.
--Forecaster is concerned only with making the best forecast possible (not with making the operational decision also).
--Can be used with quantitative decision-making techniques.

SLIDE 9 AWS POLICY

"AWS will pursue the systematic integration of probability forecasts into all aspects of weather support, whenever such forecasts can benefit the customer."
(AWSR 105-13)

SLIDE 10 REASONS FOR CHANGING TO PROBABILITY FORECASTS

--Improve the role of the forecaster.

--Enhance the use of weather forecasts.

SLIDE 11 — REASON FOR CHANGING: IMPROVE THE ROLE OF THE FORECASTER

Probability Forecasts:

--Allow the forecaster to express his uncertainty.
--Allow the forecaster to concentrate on the forecast.
--Can provide only the weather needed for the decision.

SLIDE 12 — REASON FOR CHANGING: ENHANCE THE USE OF WEATHER FORECASTS

Probability Forecasts:

--Provide more information.
--Are consistent.
--Can be used with quantitative decision-,aking techniques.
--Can be more cost/mission effective in the long term.

SLIDE 13 — EXAMPLE

Setting: Division on attack. 1st Bde is close to making a breakthrough. To exploit, Division needs a bridge 20 km behind enemy lines.

Problem: Determine best way to capture the bridge with a battalion size force.

Courses of Action: C/A 1: Airborne
C/A 2: Air Assault
C/A 3: Task force from 1st Bde

Decision Variables: M E T T

SLIDE 14. COMMANDER'S ANALYSIS OF COURSES OF ACTION

C/A 1 chosen/Type B weather occurs: The clouds which hide the aircraft from the enemy's antiair weapons will also reduce the accuracy of the troops to reach the desired area. Commander assigns a utility of 5.

C/A 1 chosen/Type C weather occurs: Troops will not be able to make the jump. Commander assigns a utility of 0.

C/A 2 chosen/Type A weather occurs: Assault can be accomplished, but some aircraft losses must be expected due to good visibility for enemy air defense. Commander assigns a utility of 6.

C/A 2 chosen/Type B weather occurs: Clouds and visibility low enough to hinder enemy air defense, but not low enough to prevent mission. Commander assigns a utility of 10.

C/A 2 chosen/Type C weather occurs: Fog obscures terrain to such an extent that mission is impossible. Commander assigns a utility of 0.

C/A 3 chosen/Type A weather occurs: Weather does not affect the task force, but it can not complete mission as fast as the commander wants. He assigns a utility of 3.

C/A 3 chosen/Type B weather occurs: Weather does not affect the task force, but it can not complete mission as fast as the commander wants. He assigns a utility of 3.

C/A 3 chosen/Type C weather occurs: Fog will hide the attack of the task force and should allow it to accomplish the mission quicker. Commander assigns a utility of 5.

SLIDE 15. UTILITY OF C/A IN MATRIX FORMAT

		Weather		
		Type A	Type B	Type C
Commander's Decision	C/A 1	8	5	0
	C/A 2	6	10	0
	C/A 3	3	3	5

SLIDE 16 **CHOOSING A C/A**

Weather Forecast:

Weather Type	Probability
A	70%
B	20%
C	10%

Computing Expected Value of C/A:

C/A 1: $8 \times .7 + 5 \times .2 + 0 \times .1 = 6.6$
C/A 2: $6 \times .7 + 10 \times .2 + 0 \times .1 = 6.2$
C/A 3: $3 \times .7 + 3 \times .2 + 5 \times .1 = 3.2$

Choice: C/A 1 (Airborne Operation)

SLIDE 17 **CHOOSING A C/A**

Weather Forecast:

Weather Type	Probability
A	60%
B	40%

Computing Expected Value of C/A:

C/A 1: $8 \times .6 + 5 \times .4 + 0 \times 0 = 6.8$
C/A 2: $6 \times .6 + 10 \times .4 + 0 \times 0 = 7.6$
C/A 3: $3 \times .6 + 3 \times .4 + 5 \times 0 = 3.0$

Choice: C/A 2 (Air Assault)

SLIDE 18 **ALTERNATIVE DECISION METHOD**

Choose C/A 1 if $P > P_c$

C/A 2 if $P < P_c$

Either if $P = P_c$

where P = Forecast Probability

P_c = Critical Probability

SLIDE 19 — CRITICAL PROBABILITY

$$P_c = \frac{C - D}{B + C - A - D}$$

		Weather Unfav	Weather Fav
Decision	C/A 1	A	B
	C/A 2	C	D

Critical Probability Computation:

--Dollar values for A, B, C, D
--Utility values for A, B, C, D
--Modeling
--P_c = climatological probability

SLIDE 20 — POTENTIAL PROBLEMS

--Forecaster/user understanding
--Forecaster can not prepare skillful, reliable forecast
--Increased user workload
--User concentration on present decision

SLIDE 21 — POTENTIAL PROBLEM: MEANING OF PROBABILITY FORECASTS

1. The probability that measurable rain (i.e., 0.01 inch or more) will fall somewhere within the forecast area sometime during the period covered by the forecast.

2. The probability that a general rain will cover the area.

3. The fraction of the forecast area that will receive measurable rain in the forecast period.

4. The fraction of the time interval during which measurable rain falls.

5. The probability that a traveler in the forecast area will encounter rain during the forecast period.

6. The probability that a specific point in the forecast area will receive measurable rain sometime during the forecast period.

SLIDE 22 — POTENTIAL PROBLEM: ADEQUATE FORECAST ACCURACY

Forecasters must have

--Training
--Practice
--Verification Feedback

SLIDE 23 POTENTIAL PROBLEM: INCREASED USER WORKLOAD

Users must

--Define important weather elements for decisions.
--Determine decision thresholds.
--Understand probability forecasts.
--Determine critical probability.
--Make the decision.

SLIDE 24 POTENTIAL PROBLEM: USER CONCENTRATION ON PRESENT DECISIO

Users must

--Choose best C/A for situation at hand by considering the consequences and probability of consequences.
--Realize that the next decision may not be correct.
--Seek to maximize gains (or minimize losses) in the long term.

SLIDE 25 METHODS FOR OVERCOMING POTENTIAL PROBLEMS

--Education
--Training
--Practice

SLIDE 26 CONCLUSION AND RECOMMENDATION

Conclusion: Army commanders would benefit from receiving probability weather forecasts.

Recommendation: (Tailored to requirements of the customer)

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